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HOW INFORMATION TECHNOLOGY INFLUENCES PATENTING INNOVATION: A KNOWLEDGE RECOMBINATION PERSPECTIVE

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ABSTRACT

Information technology (IT) investment is important for the production of patenting innovation. To better understand IT and innovation relationship, we theorize IT-enabled innovation process as a firm's efforts of recombining existing knowledge and the scope of recombined knowledge. Using large-scale panel data, we find empirical evidence corroborating our theory.

INTRODUCTION

Information technology (IT) is an operand organizational resource for the production of patenting innovation. In the prior literature, IT has been conceptualized as a key organizational resource that can be used to produce a firm's patenting innovation outputs (Joshi, Chi, Datta, and Han, 2010; Kleis, Chwelos, Ramirez, and Cockburn, 2012; Xue, Ray, and Sambamurthy, 2012). However, a literature review on prior studies linking IT and patenting innovation reveals a critical gap in our extent understanding. While the theoretical argumentation in prior studies often assumed IT's ability to enable the innovation process that produces patenting innovation outputs, what exactly the innovation process is and how IT influences the resulting innovation outputs through this process have not been systematically theorized nor empirically examined. In other words, the IT-enabled innovation process for knowledge production was theorized as a black box in prior research (see Figure 1, Kleis *et al.*, 2012: 47). This is a surprising gap in the literature with regard to the implications of IT for innovation, because there may be *complex* and even *opposite* intermediate mechanisms underlying the innovation process between IT and patenting innovation outputs. Thus, deepening our understanding of the innovation process through which IT is invested in and deployed for producing new knowledge can provide valuable implications for a better digital innovation strategy (Yoo, Henfridsson, and Lyytinen, 2010).

To open up the black box of innovation process through which IT influences patenting innovation outputs, we draw on the *knowledge recombination perspective* to explain a firm's innovation process (Fleming, 2001). This powerful theoretical foundation suggests that a patenting innovation can be viewed as a recombination of existing knowledge components from prior patents. Accordingly, we characterize the innovation process by two critical aspects of knowledge recombination: the efforts of recombination are put and the scope of knowledge that is recombined. Specifically, we theorize *knowledge recombinant intensity* as the extent to which a firm recombines existing knowledge, and *knowledge recombinant diversity* as the degree to which a firm recombines knowledge from different domains. We develop a research model

proposing IT as a key organizational resource enabler increasing a firm's knowledge recombinant intensity and diversity, which in turn influence its patenting innovation outputs.

Besides seeing the innovation process as a black box, other limitations also exist in the prior literature. Most past studies relied on aggregate IT investment, and while this measure can accurately indicate the scale of a firm's IT resources, it does not provide the details about what specific technologies are invested in and used by a firm. In this study, we incorporate both aggregate IT investment and more granular measures for different types of IT infrastructure (i.e., computing, networking, storage and human resources), which is critical to innovation but understudied in the past (Yoo *et al.*, 2010). Furthermore, prior studies mainly investigated the impact of IT on the quantity of innovation outputs, which cannot indicate the value of innovation. In this study, we enrich the conceptualization of patenting innovation outputs by incorporating the often overlooked quality aspect, which reflects the value of patenting innovation with regard to future applications.

THEORY AND HYPOTHESES

Innovation as a Knowledge Recombination Process

We characterize a firm's knowledge recombination process by two key factors that determine innovation outputs: the efforts of recombining knowledge and the scope of knowledge that is recombined. When innovation is seen as a knowledge recombination process, this indicates that firms need to deploy organizational resources to exert efforts to support this process. Moreover, the scope of knowledge that is used for recombination determines the richness of recombinant possibilities. As a result, we theorize *knowledge recombinant intensity* as the amount of existing knowledge that a firm recombines, and *knowledge recombinant diversity* as the degree to which a firm recombines existing knowledge from different domains. We develop a model proposing IT and R&D resources as key enablers that facilitate knowledge recombinant intensity and diversity, which in turn influence patenting innovation outputs. Since our study is focused on IT and innovation, we theorize the role of IT in the innovation process and control the impact of R&D investment in the empirical analysis.

Hypotheses Development

IT investment contributes to a sophisticated IT infrastructure in the support of internal knowledge flows within a firm and external knowledge transfers to a firm (Yoo *et al.*, 2010). We propose that a firm's IT investment can build a sophisticated IT infrastructure, which accelerates dissemination of internal knowledge and facilitates the assimilation of external knowledge by enabling efficient research communication and collaboration. For example, the adoption of computing and networking technologies supporting Internet protocol-based email and telephony can increase the efficiency of communication and facilitate the exchange of scientific knowledge among researchers in a firm's dispersed R&D centers, who may otherwise have relatively few alternative means of communication (Forman and Zeebroeck, 2012). In addition, company-wide database and knowledge repositories can help disseminate codified knowledge among researchers in a firm by increasing their access to scientific information from scholarly journals and scientific data from prior experiments. With a sophisticated IT infrastructure, digitized knowledge can be not only communicated in a formal and bidirectional way among researchers,

but also transferred in an informal and unidirectional search manner to a single researcher. The aforementioned IT infrastructure can also enable a firm to assimilate external knowledge in collaboration with researchers from other firms in R&D alliances (Dong and Yang, 2015). A greater amount of knowledge from internal and external sources provides more useful components for recombination, and thereby supports the more intensive recombinant efforts.

Hypothesis 1: IT investment positively affects knowledge recombinant intensity.

As innovation research has begun to understand innovation as a knowledge recombination process based on existing knowledge components, it has become apparent that a more open and interactive innovation model is required to collect various sources of knowledge (Fleming, 2001). In addition to enabling more recombinant efforts, a sophisticated IT infrastructure resulted from IT investment also allows a broader search spectrum across a wide range of knowledge domains. We propose that IT investment can increase a firm's access to a wide scope of knowledge domains, which brings a variety of knowledge components from different domains that can be recombined. For example, the adoption of computing and networking equipment allows a firm's researchers to use email, instant message and collaborative tools, which enhances the richness of their communication and the exchange of knowledge from a variety of research areas (Daft, Lengel, and Trevino, 1987). Storage capacity may also aid the recombination process by facilitating the accumulation and retrieval of diverse knowledge to and from a firm's researchers and external partners. A sophisticated IT infrastructure also helps build a common language platform to create a common form of communication among researchers with different knowledge backgrounds, so that they can integrate their specialized knowledge. For example, IT infrastructure compatible with advanced standards can serve as "boundary object" allowing firms to share different domain-specific knowledge in an efficient manner (Malhotra, Gosain, and El Sawy, 2007), which increases a focal firm's use of diverse knowledge from different domains in the recombination process.

Hypothesis 2: IT investment positively affects knowledge recombinant diversity.

Firms produce patenting innovation by carrying out persistent efforts in the knowledge recombination process. Intensive recombinant efforts can produce more patenting innovation outputs by identifying more recombinant opportunities. Furthermore, intensive knowledge recombination allows a firm to get familiar with more knowledge components that are relevant to the specific tasks in the innovation process. Such intensive efforts can accumulate recombinant experience and domain-specific task advice, leading to the accumulation of firm-specific heuristics (i.e., how to identify valuable knowledge components and recombine them in a better architecture) that are critical to the innovativeness of the resultant recombination (Henderson and Clark, 1990). Intensive knowledge recombination process is thus not only able to increase the amount of patenting innovation outputs, but also likely to recombine more valuable knowledge components and generate high quality patenting innovation with a big impact on various subsequent knowledge inventions. In summary, we propose that firms with greater knowledge recombinant intensity are likely to produce a larger quantity and a higher quality of patenting innovation outputs.

Hypothesis 3a: Knowledge recombinant intensity positively affects patenting innovation quantity.

Hypothesis 3b: Knowledge recombinant intensity positively affects patenting innovation quality.

Greater knowledge recombinant diversity means bigger leaps into new knowledge territory. On the one hand, it becomes more difficult to overcome the complexity of recombination and successfully recombine knowledge components if the knowledge components come from a variety of different domains, and on average this results in a lower rate of successful recombination (Fleming, 2001). We thus propose that, holding other factors constant, firms with greater knowledge recombinant diversity produce a smaller quantity of patenting innovation outputs. On the other hand, the knowledge components from various domains are able to offer greater possibilities of generating highly innovative outputs. The most valuable opportunities for innovation often arise from bridging different knowledge domains, which lead to breakthrough inventions (Fleming, 2001). Patenting innovation from a process of bringing together apparently distinct knowledge is likely to be more useful for a wide range of applications in the future, which therefore has higher quality (Carnabuci and Operti, 2013). We thus further propose that greater knowledge recombinant diversity can increase the likelihood of discovering better recombinant opportunities and a higher quality of patenting innovation outputs.

Hypothesis 4a: Knowledge recombinant diversity negatively affects patenting innovation quantity.

Hypothesis 4b: Knowledge recombinant diversity positively affects patenting innovation quality.

METHODS AND RESULTS

We adopt a longitudinal design and collect archival data from multiple sources to test our hypotheses. First, we obtained IT spending data from *InformationWeek* (IW), which is a well-known business magazine with a focus on IT in business, and annually published special issues about the IT budgets of the top 500 firms that were the leading IT users in the period 1991 to 1997. The data were compiled in an annual survey for IT chief managers conducted by the Harte Hanks' Computer Intelligence (CI) Corporation, a leading market research company. IT spending was defined as corporate-wide capital and operating expenditure on IT. IW 500 is widely seen as a high-quality source of IT investment data, and has been used in much prior research. We augmented the IT investment data with more detailed IT measures from Harte Hanks' CI Technology database. CI Technology database provides detailed information about firms' use of various technologies at the company site level, although it does not provide IT spending information. We obtained IT use data for a more recent period, from 2001 to 2003, and calculated count measures for four different types of IT infrastructure (i.e., computing, networking, storage and IT labor infrastructures) at the firm level. Second, we merged IT data with financial data from Standard and Poor's Compustat database for U.S. public firms. Finally, we collected patent and citation data from the National Bureau for Economic Research (NBER) Patent Citations database (Hall, Jaffe, and Trajtenberg, 2001), which has been widely used in the

past research on IT and innovation to measure patenting innovation outputs. After merging the above data sources we obtained a final sample of 1,598 firm-year observations from 496 firms in 1991 to 1997 for our main analysis. We produced another sample with granular measures for different kinds of IT infrastructure to test H1 and H2, consisting of 4,059 firm-year observations from 1,622 firms in 2001 to 2003.

We measure IT investment by a firm's total IT spending scaled by total sales. To complement our main measure of aggregate IT investment, we further construct more specific measures for IT infrastructure. We measure computing infrastructure as the count of servers and PCs used by a firm, scaled by the number of employees. Similarly, networking infrastructure is measured by the count of local area network (LAN) nodes used by a firm over the number of employees. Storage infrastructure is measured by the storage capacity in gigabytes used by a firm per employee. Finally, we measure IT labor infrastructure as the percentage of employees who are IT personnel recruited by a firm. We include R&D investment as another important resource input to the innovation process, which is measured by a firm's total R&D spending scaled by total sales. We measure knowledge recombinant intensity based on the total number of *backward* citations that a firm made in a specific year. We rely on the originality measure to capture knowledge recombinant diversity (Hall *et al.*, 2001). We use simple count of patents and *forward* citation-weighted count of patents to measure patenting innovation quantity. We further use the generality measure to capture patenting innovation quality (Hall *et al.*, 2001). Finally, we control related diversification, unrelated diversification, capital intensity, financial leverage, firm growth, firm size, and industry and year dummies.

IT investment was found to have statistically significant and positive effects on knowledge recombinant intensity ($\beta = 10.718, p < 0.01$) and knowledge recombinant diversity ($\beta = 0.666, p < 0.1$), after controlling R&D investment and other factors. Thus, H1 and H2 were supported. Furthermore, we found that computing, networking and storage infrastructures had statistically significant and positive effects on knowledge recombinant intensity, and IT labor infrastructure did not. Moreover, computing and networking infrastructures had statistically significant and positive effects on knowledge recombinant diversity, but storage and IT labor infrastructures did not. We found that knowledge recombinant intensity had statistically significant and positive effects on (simple/weighted) patenting innovation quantity ($\beta = 0.693, p < 0.01$; $\beta = 0.932, p < 0.01$) and patenting innovation quality ($\beta = 0.043, p < 0.01$). Thus, H3a and H3b were supported. In addition, knowledge recombinant diversity also had a statistically significant and positive effect on patenting innovation quality ($\beta = 0.370, p < 0.01$), and a statistically significant and negative effect on (simple/weighted) patenting innovation quantity ($\beta = -1.439, p < 0.01$; $\beta = -1.062, p < 0.01$). Thus, H4a and H4b were also supported.

CONCLUDING REMARKS

Our research makes three major contributions to the IT and innovation literature. First, drawing on the knowledge recombination perspective, we open up the black box of innovation process by theorizing and testing knowledge recombinant intensity and diversity as the missing links between IT and patenting innovation outputs. Second, we not only rely on aggregate IT investment, but also theorize and examine the impacts of different IT infrastructure types on the innovation process. Finally, we enrich the conceptualization and measurement of patenting innovation outputs by simultaneously considering both the quantity and quality aspects, and find the nuanced role of IT in supporting these different aspects of innovation.

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